Technical memorandum

SINGLE-LAYER MULTIBAND FREQUENCY-SELECTIVE SURFACES

Indexing terms: *Antennas, Microwave circuits and networks*

Abstract: Future multimission communications satellites will require a single reflector antenna to operate at three or more frequency bands. The paper describes the frequency responses of two single-layer frequency-selective surfaces suitable for this application, together with their crosspolar performance. These surfaces are alternatives to multilayer FSS currently being proposed and generally offer better crosspolarisation performance with reduced mechanical complexity.

Multiband arrays

Future multimission satellites will carry payloads operating at a number of different frequency bands, e.g. 1.5, 4/6, 11/14 and 20/30 GHz. In order to accommodate these services, and satisfy weight and space constraints, antennas are required which will operate at three or more of these bands. A single reflector antenna can be used at multiple frequencies by employing frequency selective surfaces (FSS) to separate the individual bands. One such configuration operating at three frequency bands is shown in Fig. 1.

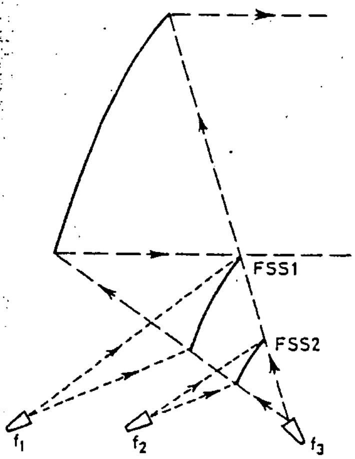

Fig. 1 *Three-frequency-band reflector antenna incorporating two frequency-selective surfaces, FSS1 and FSS2*

Here the bands f_1, f_2 and f_3 are separated by two mirrors FSS1 and FSS2. in Fig. 1, FSS2 is required to separate two frequency bands, that is, reflect f_2 and transmit f_3, and might, for example, comprise an array of concentric rings or gridded squares [1]. FSS1, however, must transmit two bands f_2 and f_3, while reflecting f_1. In addition, FSS1 must be designed for a wide range of reflection/transmission band ratios varying from 1.3 to 3 : 1. Previously only multiple layer FSS have been designed, with transmission characteristics suitable for multiband applications [2]. However, where crosspolar performance is critical, multilayer surfaces often have higher crosspolar levels than single layers [1, 3]. In this paper we present two single-layer surfaces which are suitable for use as multiband FSS and discuss their crosspolar performance.

The double-square array [4] has been studied for use in dual-band reflector systems, the features of interest in that case being the main array resonance and the relatively narrow band transmission region lying above it in frequency. However, below the main resonance there is also a transmission band extending to very low frequencies, and this is of considerable interest for multiband applications where very wide passbands are often needed (50% +). Past studies have shown that, in general, the transition from transmission to reflection is gradual, and band spacings of 3 : 1 or more in frequency are typical for this array whereas for multiband work ratios of less than 1.5 : 1 may be required. Analysis using the equivalent circuit model derived for the double square [4] reveals that the transition from transmission to reflection can be sharpened considerably by increasing the inductive and reducing the capacitative components of the elements. This results in widely spaced elements on the array but allows the band spacing to be reduced to about 1.7 at present. Fig. 2 shows

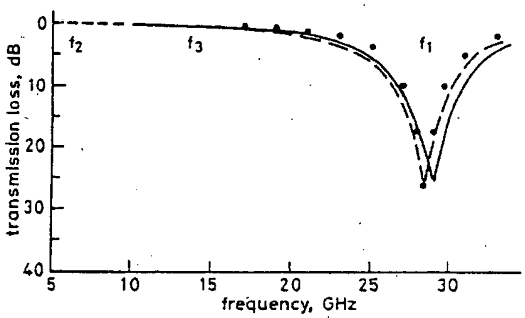

Fig. 2 *Measured transmission response of a double-square array operating at three or more frequency bands*

Periodicity $p = 4.5$ mm conductor widths $w_1 = w_2 = 0.15$ mm, element spacing $g_1 = 1.46$ mm.
——— normal incidence (see Reference 1 for array geometry)
········ 45° TM-incidence
– – – – 45° TE-incidence

the frequency response for three cases of wave incidence for a double-square FSS designed for the 6/14/28 GHz bands. The spacing between individual elements is 1.46 mm and, despite the consequent decrease in mutual coupling, the frequency bands remain largely insensitive to changes in angle of incidence. The main resonance occurs at 29 GHz for normal incidence and 28.3 GHz at 45° for both TE- and TM-incidence. A reflection bandwidth of 9% common to angles of incidence up to 45° was measured. Bandwidths are measured between the 0.5 dB loss points for both reflection and transmission. The edge of the transmission band is determined by the 45° TE-incidence response, and at the 14 GHz band edge, i.e. at 14.5 GHz, the transmission loss is 0.4 dB. All bands below 14 GHz are passed without significant attenuation, and 1.5 GHz could be added to the system without redesign of the FSS. Improvements in the manufacturing process may allow even closer band spacings, perhaps ~ 1.5.

When more closely spaced sets of bands must be separated, e.g. 11/14/19 GHz, a new hybrid array element can be used, the gridded double-square FSS (see inset in Fig. 3). Band spacings in the range of 1.2 to 1.6 may be achieved using this array. The addition of a grid [5, 6] to the double-square array causes a narrowing of the low-frequency transmission band and provides a much sharper transition from reflection to transmission. A second passband lies above the reflection band. The transmission characteristics of gridded double-square array 3 in Table 1 is

Table 1: Gridded double-square array dimensions and frequency characteristics

Array	Dimensions, mm						Bandcentre, GHz			Band ratio		Bandwidth, %		
	p	w_1	w_2	w_3	g_1	g_2	f_2	f_1	f_3	f_1/f_2	f_3/f_1	Δf_2	Δf_1	Δf_3
1	5.1	0.19	0.2	0.98	0.65	0.23	15.9	21.8	28.1	1.37	1.29	20	5	9
2	5.1	0.2	0.2	0.58	0.21	0.6	12.0	16.5	26.2	1.38	1.59	8	8	10
3	4.5	0.32	0.2	0.26	0.37	0.37	18.0	23.5	30.5	1.3	1.3	6	8	4
4	4.5	0.15	0.2	0.2	0.19	0.25	13.5	18.9	22.8	1.4	1.2	7	6	3

(Bandwidths quoted are common to angles of incidence up to 45°, and are measured between the −0.5 dB points)

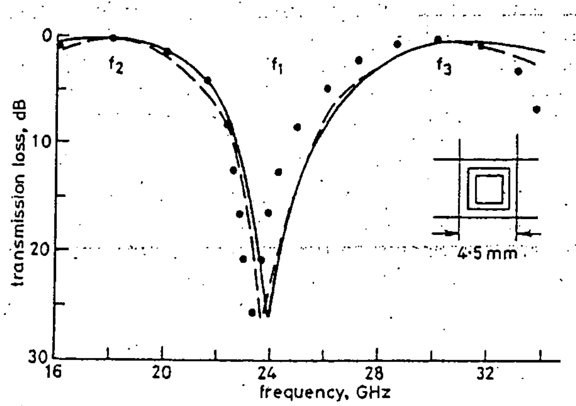

Fig. 3 *Measured transmission response of gridded double-square array 3 in Table 1, operating at three frequency bands*

——— normal incidence
········ 45° TM-incidence
– – – – 45° TE-incidence

shown in Fig. 3. In this case the two pass bands f_2 and f_3 are centred on 18.0 and 30.5 GHz, respectively, and lie on either side of the main array resonance f_1 at 23.5 GHz. Bandwidths common to all angles up to 45° incidence are 6%, 4% and 8%, respectively, with band-spacing ratios of $f_3/f_1 = 1.3 = f_1/f_2$. Again, the array is relatively insensitive to changes in the angle or plane of incidence. Interestingly, if the centre frequencies shown in Fig. 3 are scaled by a factor of 0.61 then they correspond to the 11, 14 and 19 GHz bands, respectively.

Table 1 summarises the frequency characteristics of four gridded double-square arrays with different element geometries. The bandwidths available are broadly determined by the required band-spacing ratio, closer ratios giving narrower bandwidths. It appears that, in general, bandwidths can be optimised by choosing the grid period p as large as is consistent with avoiding grating responses near the upper-frequency band centred at f_3. A design procedure based on an equivalent circuit analysis is currently being studied.

The peak crosspolarisation levels measured for gridded double-square array 3 over its three operating bands are shown in Fig. 4. Measurements were made in the 45° diplexer discussed in Reference 3. The incident fields are pure TE and TM at the centre of the array only. For the lower-frequency transmission band at 18 GHz the levels are less than −34 dB, whereas in the reflection band at 23 GHz levels better than −36 dB were recorded. Peak feed levels are only marginally below those measured for the FSS array. However, crosspolar levels measured over the upper transmission band (29 GHz) vary from −35 dB at the lower band edge, rising to −30 dB at the upper edge. The rise in levels towards the higher frequencies is currently being investigated. Similar crosspolar levels were also measured for the double-square array. Crosspolar levels for the four-layer inductive grid FSS presented in Reference 3 ranged from −20 to −35 dB in transmission and from −25 to −30 dB in reflection. These levels on

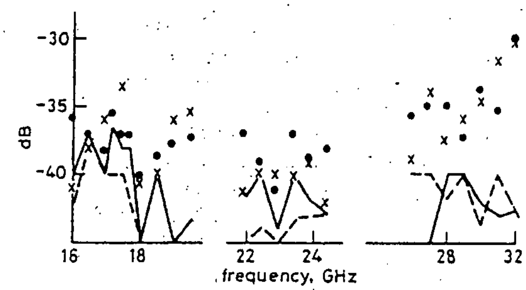

Fig. 4 *Peak 45° plane crosspolarisation for gridded double-square array 3 in Table 1*

× × × 45°—TM } FSS
·· 45°—TE }
– – – – 45°—TM } Feed alone
——— 45°—TE }

average are at least 5 dB higher than those measured for the single-layer gridded double square presented above.

In conclusion, we have demonstrated two single-layer FSS which can be used as alternatives to multiple-layer structures in multiband antennas with an expected improvement in crosspolar performance and reduced mechanical complexity.

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